DOCUMENT RESUME

ED 155 586 CS 004 057

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TITLE Reading Disability and Visual Perception in Families: New Findings.
PUB DATE Mar 78
NOTE 61p.; Paper presented at the Annual Meeting of the American Educational Research Association (Toronto, Canada, March 27-31, 1978)

EDRS PRICE MF-$0.83 HC-$3.50 Plus Postage.
DESCRIPTORS Cognitive Development; Elementary Secondary Education; *Family Characteristics; *Learning Disabilities; Parents; *Perceptual Development; Reading Ability; *Reading Difficulty; *Reading Research; Visual Discrimination; *Visual Perception

ABSTRACT

Frequently a variety of visual perception difficulties correlate with reading disabilities. A study was made to investigate the relationship between visual perception and reading disability in families, and to explore the genetic aspects of the relationship. One-hundred twenty-five reading-disabled students, ages 7.5 to 12 years, were matched with an equal number of students from a control group; parents and all available siblings of comparable age for both groups were also studied. The affected students had IQs of 90 or above and had no obvious psychological or physical difficulties, but they were reading at or below one-half the expected grade level. Results indicated a strong relationship between reading disability and visual perception, suggesting that visual perception is indeed very important in some types of reading disability. Significant sex and family type effects appeared, supporting the familial nature of learning disability. However, data indicating sex-linked major gene transmission were not found. It was concluded that reading disability is strongly related to visual perception, and that both are familial. (DF)

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Reading Disability and Visual Perception in Families: New Findings

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This paper was presented at the meeting of the American Educational Research Association in Toronto, Ontario, Canada, March 27-31, 1978. It is based on the author's doctoral dissertation at the University of North Carolina. The research was part of the Colorado Family Reading Study, which was supported in part by a grant from the Spencer Foundation and was directed by Dr. John C. DeFries of the Institute for Behavioral Genetics, University of Colorado. The author is currently affiliated with the Social Science Education Consortium, Boulder, Colorado.

Running Head: Reading Disability and Visual Perception

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Abstract

This study investigated the relationship between reading disability and visual perception in 250 families (n = 1,044). A strong relationship was found, as shown by a canonical correlation of .646 within the entire sample with 41.7% of the variance in reading scores explained by visual perception scores.

The familial nature of reading disability and visual perception was supported by several types of data: canonical correlations for affected and control subsamples, analysis of variance results on canonical variate scores, and genetic analyses of canonical variate scores.

Educational implications and future research directions were also discussed.

Reading Disability and Visual Perception in Families: New Findings

Approximately ten per cent of school-aged children in the United States and other Western Hemisphere countries have a reading disability, i.e., an unexpected reading impairment in the absence of obvious causes such as poor teaching, mental retardation, emotional disturbance, brain injury, or environmental disadvantage (Critchley, 1973; DeFries, Vandenberg, & McClearn, 1976; Foch, 1975). Although the exact causes of reading disability are unknown, certain correlates of reading disability frequently appear. Among these correlates are a variety of visual perception difficulties. Comprehensive reviews of studies on visuoperceptual problems related to reading are given by Oxford (1978) and Vernon (1973).

Figure 1 presents an iconic model of learning problems and indicates the general relationship between reading disability and visual perception (proportions not to scale). As shown in Figure 1, not all reading disabled individuals have visuoperceptual problems, and not all people with visuoperceptual problems are disabled in reading; however, there is a great amount of overlap.

Insert Figure 1 about here

Many visuoperceptual problems are more prevalent among younger reading disabled subjects than among older ones (see research review by Oxford, 1978). Such problems include (a) visual discrimination, i.e., differentiation of one object from another or the matching of like objects; (b) object recognition, i.e., identification of shapes, objects, words, letters, and numbers regardless of their patterning, color size, or position; (c) visual closure, i.e., identification of an object from viewing a part of it; (d) directional sense, i.e., discrimination between left and right and between upside-down and right-side up; (e) visual-motor coordination, i.e., integration of vision or visual perception with body movement; (f) sequential crossmodal matching, i.e., identification of similarity between items in two modalities, such as sounds and letters; (g) sequential intramodal matching, i.e., identification of similarity between items within one modality, such as dots and flashes, both in the visual modality; and perhaps (h) crossmodal integration, i.e., coordination of visual and auditory stimuli. Some visuoperceptual problems do not tend to disappear or become less severe with age, however. Among these are visual memory, i.e., the ability to store and retrieve visual information, and visual

symbolization, i.e., mental representation of an object by a visual image. For other visuoperceptual problems, including deficits in spatial relations perception and figure-ground discrimination, there is insufficient research evidence to say whether these problems decrease with age.

Despite the fact that the exact relationship between visuoperceptual problems and reading disability is unclear, a host of remedial reading programs has been designed based on improvement of visuoperceptual skills or perceptuomotor skills (Barsch, 1965, 1967; Delacato, 1963; Fernald & Keller, 1921; Frostig & Horne, 1964; Getman, 1965; Gillingham & Stillman, 1936, 1965; Johnson & Myklebust, 1967; Kephart, 1960, 1964). Findings have been mixed concerning the efficacy of perceptual programs for improving reading (Kaufman, 1973; Torgesen, 1975).

Reading ability, visual perception ability, and various deficits in those two areas have been found to have a highly familial nature, i.e., members of the same family have frequently been observed to have similar reading ability or visual perception ability (see review of twin and family studies by DeFries, Vandenberg, & McClearn, 1976). Many different genetic transmission models have been investigated for reading disability and

visual perception ability. Sex-linked transmission models, which have sometimes been championed in the past, are now being rejected in light of increased research evidence favoring other models (DeFries, Ashton, Johnson, Kuse, McClearn, Rashad, Vandenberg, & Wilson, 1976; DeFries, Vandenberg, & McClearn, 1976; Foch, DeFries, McClearn, & Singer, 1977; Kuse, Note 1; Morton, Yee, Elston, & Lew, 1970). Although there is ample evidence that reading and visual perception have some genetic components, it is clear that environment also contributes to the familial nature of both abilities (Foch, DeFries, McClearn, & Singer, 1977).

This study investigates the relationship between visual perception and reading disability in families and explores some genetic aspects of the relationship.

Method

Subjects

The Colorado Family Reading Study (CFRS), upon which this investigation is based, involved the families of 125 reading disabled children and 125 matched controls, or 1,044 individuals. The sample included the probands (reading disabled children), their matched controls, the parents of probands and controls, and all

available siblings (aged 7 to 18).

Probands were selected from the referrals of teaching specialists and school psychologists in two Colorado school districts (Boulder Valley and St. Vrain Valley School Districts), which included 44 elementary schools, and from the Boulder County Developmental Evaluation Clinic (Foch, 1975). Probands were children with diagnosed reading problems who met the following criteria: (a) 7.5 to 12 years of age; (b) reading performance equal to or less than one-half the expected grade level expected as measured by a standardized test (e.g., a child in the fourth grade reading at or below second-grade level); (c) IQ of 90 or higher on a standardized IQ measure; (d) no obvious psychiatric, neurological, or uncorrected visual or auditory acuity problems; e) living with both biological parents.

Each proband was matched with a normal reader on the basis of sex, age (within six months), grade in school, school environment (from the same school, if possible), and home neighborhood. Matched controls were required to meet all of the selection criteria for probands except that reading achievement level, as measured by a standardized test, had to be equal to or greater than grade level expectancy.

Numbers of individuals in each category in the 250 families are displayed in Table 1. The term "affected" indicates that the family contains a reading disabled proband. The term "control" denotes that the family does not contain a reading disabled proband. Table 1 shows that there were many more males than females among the probands (affected index children). Male probands outnumbered female probands at a ratio of more than three to one (3.3:1) with 96 male probands and 29 female probands included. This finding is congruent with results of previous studies.

Insert Table 1 about here

Table 2 gives the mean ages in each category. This table shows that the mean ages of individuals within each "affected" category (i.e., fathers of affected index children, or probands; mothers of affected index children; male affected index children; female affected index children; male sibs of affected index children; female sibs of affected index children) were quite similar to the mean ages of individuals within each corresponding "control" category.

Insert Table 2 about here

A factor-score analysis was conducted in which subjects were classified as either reading disabled or not reading disabled according to their reading factor score, which was found through a principal components procedure. Results of the factor-score analysis indicated that in the control families, 17.5% of the subjects were classified as reading disabled, while in the affected families, 52.9% were classified as reading disabled (Lewitter, 1975). That is, there were over three times as many reading disabled individuals in families or probands than in families of controls.

Tests

An extensive battery of tests was administered to probands, their parents and sibs, and members of matched control families between November 1973, and June 1975, at the Institute for Behavioral Genetics at the University of Colorado. Each individual was paid $10.00 for participation.

The original battery, which was administered to the first 58 matched families, took approximately four hours. In the original CFRS battery, two sets of tests were

used, one for subjects under 10 and the other for subjects 10 and over (including parents). A large number of tests overlapped; that is, they were used with all ages. Names and sources of all tests administered in the original battery are shown in Table 3.

Insert Table 3 about here

The original battery was reduced to include only those tests which had high reliability and which maximally differentiated between affected and control children, as shown by discriminant function analysis (Foch, 1975). Table 4 gives names of tests in the reduced CFRS battery which took approximately 2½ hours to administer.

Insert Table 4 about here

This study of visual perception and reading disability involves 8 of the 10 tests in the reduced battery. Selection criteria are explained by Oxford (1978). Three reading-related subtests of the Peabody Individual Achievement Test (Dunn & Markwardt, 1970) were selected: (a) Reading Recognition Subtest (abbreviated RREC in this study); (b) Reading Comprehension Subtest, or RCOMP; and (c) Spelling Subtest, or SPELL. Five instruments were chosen to measure various aspects of visual perception skills: (a) Benton Left-Right

Orientation Test, or BENT (Benton, 1959); (b) Nonverbal Culture Fair Intelligence Test, or IPAT (Institute for Personality and Ability Testing, 1973); (c) Wechsler Intelligence Scale for Children, Form B, Coding Subtest, or CODE (Wechsler, 1949); (d) Primary Mental Abilities Test, Spatial Relations Subtest, or PMA (Thurstone, 1963); and (e) Colorado Perceptual Speed Test: Rotatable Letters and Numbers, or PSPEED (Meredith, Singer, & DeFries, Note 2). Complete information on reliability, validity, number of items, length of administration, etc., may be found in Oxford (1978).

Table 5 shows (a) the name of each test included in the study, (b) its abbreviation, (c) its general item content, and (d) its visuoperceptual content classification. Visuoperceptual content classification of tests is based on analysis of item content. For example, groups of items involving matching of identical letters would be classified as a "visual discrimination" task, whereas a set of items requiring choice of an object to complete a series would be labeled "visual closure." A given test can have more than one visuoperceptual content classification, because a test can have item groups which display markedly different content. One outstanding feature is that all the tests, even the

reading tests, can be classified according to the visuoperceptual categories. As shown in Table 5, the following general visuoperceptual content classifications apply: visual discrimination (RREC, SPELL, IPAT, PSPEED); object recognition (RREC, SPELL); spatial relations (IPAT, PMA); visual closure (IPAT, PMA); directional sense (BENT, PMA, PSPEED); visual-motor coordination (CODE); sequential crossmodal matching (SPELL,; sequential crossmodal integration not based on matching (RREC); visual symbolization (RCOMP, CODE). The only visuoperceptual area which is not covered by these tests is figure-ground discrimination.

Insert Table 5 about here

Age Adjustment and Score Standardization

In order to adjust scores for age, the total sample was divided into three age groups: (a) children under 10 years of age, (b) children from 10 to 18 years of age, and (c) adults, which operationally meant parents of index children. Separate age adjustments were employed for each group. Each subject's score on every test was expressed as a deviation from a regression line (quadratic regression of each score of members of control families on age). The basic regression equations

were derived from control data only and were applied to data from both control and affected families to enhance clarity of control-affected comparisons.

For comparability among tests, the age-adjusted test scores were transformed to t-scores with a mean of 50 and a standard deviation of 10 within each of the three age bands in the control sample.

Hypotheses and Statistical Analysis

The specific hypotheses tested were:

1. Canonical correlations between the first reading canonical variate and the first visual perception canonical variate are different in affected and control subsamples.
2. Canonical correlations between the second reading canonical variate and the second visual perception canonical variate are different in affected and control subsamples.
3. There is a significant sex effect on canonical variate scores within the entire sample and within each subsample.
4. There is a significant family-type effect on canonical variate scores within the entire sample and within each subsample.

5. The canonical variate scores do not show any sex-linked genetic transmission.
6. The midchild-on-midparent regression and the sibling correlation for canonical variate scores indicate a significant degree of heritability.
7. Spouse correlations for canonical variate scores are moderately high.

The first two hypotheses were tested with canonical correlation analysis (Cooley & Lohnes, 1971; Nie, Hull, Jenkins, Steinbrenner & Bent, 1975), which indicates the maximum correlation between two linear combinations of variables: (a) the set of three reading tests and (b) the set of five visual perception tests. Hypotheses 3 and 4 were tested with multivariate analysis of variance applied to canonical variate scores, which are calculated as follows (Nie et al., 1975, p. 519):

$$\text{canvar}_i = \text{CV}_i z_i,$$

where $\underline{\text{CV}}_1$ and $\underline{\text{CV}}_2$ are the matrices of canonical variate loadings corresponding to the first and second set of variables (canonical variates, i.e., linear combinations of variables) in a given pair. In the above equation, $\underline{z}_1$ and $\underline{z}_2$ are the vectors of standardized values of the variables in the first and second set of variables,

respectively.

The FAMCOR program (Kuse, Note 3) was used to test the last three hypotheses.

Results

Hypotheses 1 and 2

The first two hypotheses were supported by the data, although further tests are necessary to determine the significance of the differences between canonical correlations of the affected and control subsamples.

Following Cooley and Lohnes (1971, p. 177), the following notation is used in reporting canonical correlations in Tables 6 and 7. R_{c1} symbolizes the first canonical correlation, i.e., the correlation between the first reading canonical variate and the first visual perception canonical variate. R_{c2} means the correlation between the second reading and second visual perception canonical variates. The square of the canonical correlation is equal to the eigenvalue, or lambda (λ), and it indicates the amount of variance in the canonical variate which is explained by the other canonical variate in a pair. Eigenvalues are reported along with canonical correlations in Tables 6 and 7.

Insert Tables 6 and 7 about here

Affected vs. control comparisons are made here only in cases in which both parts of a given pair have significant ($p < .01$) canonical correlations. That is, if the affected subsample within a comparison pair has a significant canonical correlation and the control subsample does not, no comparison is made.

In the first canonical variate pair, canonical correlations were generally higher for members of affected families than for members of control families, as indicated by 9 out of 13 possible comparisons between afrected and control groups having significant canonical correlations. However, the other 4 of the 13 possible affected vs. control comparisons showed higher canonical correlations for members of control families than for members of affected families.

In contrast to the findings for the first canonical variate pair, members of control families generally showed higher canonical correlations than members of affected families for the second canonical variate pair. This result occurred in six of seven possible comparisons between affected and control groups having significant canonical correlations.

Furthermore, high and significant canonical correlations appeared far more frequently for the first

canonical variate pair than for the second canonical variate pair. The whole-sample canonical correlations reflect the generally higher significance in the first canonical variate pair than in the second: R_{c1} = .646 and R_{c2} = .320 for the entire sample. In the first pair, 41.7% of the variance in the reading variate is explainable by the visual perception variate. In contrast, only 10.2% of the variance in the second reading canonical variate can be accounted for by the second visual perception canonical variate.

These differences can be explained by the nature of canonical variates. The second pair of canonical variates must be orthogonal to (uncorrelated with) previously determined canonical variates. It would be expected that different patterns of correlation would be found in the first pair and the second pair of canonical variates.

The test loadings on canonical variates suggest that the maximized correlations for both canonical variate pairs were caused by the strong contributions of the following four tests: RCOMP and SPELL among the reading tests and IPAT and PSPEED among the visual perception tests.

Table 8 shows that the highest loadings on the

first reading canonical variate were .423 for RCOMP and .407 for SPELL within the entire sample, and a similar pattern appeared for control families, though not for affected families. RCOMP and SPELL consistently had the highest absolute-value loadings on the second reading canonical variate for the entire sample and for affected and control families (Table 9).

Insert Tables 8 and 9 about here

IPAT and CODE consistently contributed the most to the formation on the first and second visual perception canonical variates in the entire sample and in affected and control families, as shown in Tables 10 and 11.

Insert Tables 10 and 11 about here

The important contributions made by these four tests may be interpreted in light of their visuoperceptual content coverage, as described earlier. RCOMP involves visual symbolization, while SPELL concerns visual discrimination, sequential crossmodal matching, and object recognition. Visual discrimination is also prominent in PSPEED and IPAT, though the additional areas of directional sense (in PSPEED), visual closure (IPAT), and spatial relations (IPAT) are also covered.

Hypotheses 3 and 4

Results of Hypotheses 3 and 4 are shown in Tables 12 through 17. In these tables, canonical variate scores on the first reading canonical variate are labeled "Canvar 1." Scores on the first visual perception canonical variate are called "Canvar 2." The "Canvar 3" is used for scores on the second reading canonical variate, while "Canvar 4" refers to scores on the second visual perception canonical variate.

Because of the previously unknown nature of the canonical variate scores for the two reading-visual-perception canonical variate pairs, nondirectional predictions were used in Hypotheses 3 and 4.

Insert Tables 12-17 about here

The predicted sex effect appeared within the entire sample and within three of five subsamples: (a) parents, (b) probands and their matched controls under 10 years old, and (c) siblings 10 years old or more. When it occurred, the sex difference consistently favored males. Sex effects appeared in both multivariate and univariate analyses. In various groups, different combinations of the four canonical variate score sets showed significant sex effects.

As expected, there was a significant family-type effect within the entire sample and all five subsamples. Means were higher for affected than control families. The multivariate analyses resulted in significant family-type differences in all cases. In the whole sample and four of the five subsamples, the univariate analyses showed significant family-type differences on both Canvars 1 and 2. No significant family-type difference was found for Canvars 3 or 4 in the univariate analyses.

Results of these analyses indicate that the four sets of canonical variate scores are so constructed as to give higher scores to (a) males instead of females, and (b) affected families rather than control families. This would seem to indicate that the sets of canonical variate scores may be loading highly on phenomena that are strongly associated with reading disability. This statement is supported by the following two facts: (a) Males are known to have a far greater incidence of reading disability than females, as indicated in previous studies and in the description of the CFRS sample.
(b) Affected families have a much higher frequency of reading disability than do control families, as shown in the description of the sample. If the canonical variate scores do indeed relate clearly to reading,

disability, this is an important finding.

A significant interaction of sex and family type on canonical variate scores appeared within the total sample but not within any subsamples. The interaction in the whole sample might be due, at least partially, to the large sample size, which increased the probability of attaining statistical significance.

Hypotheses 5, 6, and 7

Hypothesis 5 deals with sex-linked transmission. If a trait were transmitted via a sex-linked, major gene, the following pattern of single-parent, single-child correlations would be found:

$$r_{FS} < r_{MD} < r_{MS} = r_{FD},$$

where F, S, M, and D represent father, son, mother, and daughter. In this analysis, the son or daughter is the index child (proband or matched control). As indicated in Table 18, the single-parent, single-child correlations for canonical variate scores (Canvars 1 through 4) failed to show the sex-linkage pattern for either affected families or control families. This data supports the hypothesis of no sex-linkage and upholds previous findings (Singer & DeFries, Note 4), which showed that none

of the 10 tests in the reduced CFRS battery followed the pattern indicative of sex-linked, major-gene transmission.

Insert Table 18 about here

However, parent-offspring correlations for canonical variate scores were often substantial, above .40, as seen in Table 18. This indicates once more the strongly familial nature of reading disability and visual perception.

In the absence of common, between-family environmental effects, the regression of midchild on midparent value is an estimate of "narrow-sense" heritability, i.e., the proportion of the phenotypic (observed) variance due to additive genetic variance only (McClearn & DeFries, 1973). Since this regression can include environmental as well as genetic effects, it is only an upper-bound estimate of heritability. Table 19 shows that the regressions of midchild on midparent canonical variate scores are significant in both affected and control families, although the largest regression is moderate in size (.34). This result lends some degree of support to the heritability of reading disability and visual perception (Hypothesis 6).

There is no significant difference between these regressions for affected and control families.

Insert Table 19 about here

When common environmental effects are absent, the full-sibling intraclass correlation is an estimate of one-half the "narrow sense" heritability (McClearn & DeFries, 1973). The sibling correlations in Table 19 show moderate heritability estimates for the first reading canonical variate for siblings of controls; the first visual perception canonical variate for siblings of both probands and controls; and for the second visual perception canonical variate for siblings of controls. These findings support Hypothesis 6. No significant differences in sibling correlation occurred between affected and control families.

Relatively little spouse correlation appeared for canonical variate scores, as seen in Table 19. Hypothesis 7 thus received very weak support. Significant, moderate spouse correlations were found for the first reading canonical variate for parents of probands and parents of controls; and for the first visual perception canonical variate for parents of probands only. Differences were insignificant between affected and control

families in terms of spouse correlations. This finding is similar to that of Singer and DeFries (Note 4), who saw little spouse correlation in affected and control families for the tests used in the reduced CFRS battery.

Discussion

The findings of this study have substantiated the expectation of a strong relationship between reading disability and visual perception, with a first-pair canonical correlation of .646 for the entire sample. In the first canonical variate pair, correlations were generally higher for affected subsamples than for control subsamples. The opposite result occurred for the second canonical variate pair, which is by definition orthogonal to (uncorrelated with) the first pair. These findings supported the proposed familial nature of reading disability and visual perception.

Reading comprehension and spelling tests contributed the most in forming the first and second reading variates, while a perceptually oriented aptitude test and a perceptual speed test loaded most highly on the first and second visual perception variates.

Significant sex and family-type (affected vs. control) effects appeared in an analysis of variance on

canonical variate scores, with higher canonical variate scores attributed to males and to affected families. This result suggests that the canonical variate scores may be highly related to reading disability, which is found more frequently among males and among families of probands. Thus, the canonical variate scores, which maximize the correlation between the reading tests and the visual perception tests, have similar statistical characteristics to reading disability. This indicates that visual perception is indeed a very important element in some types of reading disability.

As expected, a pattern of correlations indicating sex-linked, major-gene transmission for canonical variate scores was not found.

Using canonical variate scores, no significant differences were found between affected and control families for regressions of midchild on midparent, for correlations between siblings, or for spouse correlations. Regressions of midchild on midparent and sibling correlations indicated a moderate degree of "narrow sense" heritability.

Throughout all these results run two main threads: The strong correlation between reading disability and visual perception and the familial nature of the two.

Adequate screening and diagnosis can lead to appropriate treatment of visuoperceptual problems which often accompany reading disability. Awareness of the familial nature of reading disability and visual perception can help parents and educators spot potential reading and visuoperceptual problems in families.

However, more research is needed in several areas related to reading disability and visual perception. First, there is a need for longitudinal studies of sufficiently large samples of reading disabled children to determine whether such children ever fully catch up with their age-mates in reading and supporting visuoperceptual skills, either through remedial work or maturation. Second, controlled experimental studies need to be done on the effectiveness of perceptual programs for improving reading skills. Third, there is a need for more research on the relationship between reading disability and visual perception in different cultures and various socioeconomic groups. Fourth, further tests should be done to assess the significance of the difference between reading-visuoperceptual canonical correlations in affected and control subsamples. Fifth, more studies should be conducted on heritability and on environmental-genetic interactions and correlations for reading disability and visual perception.

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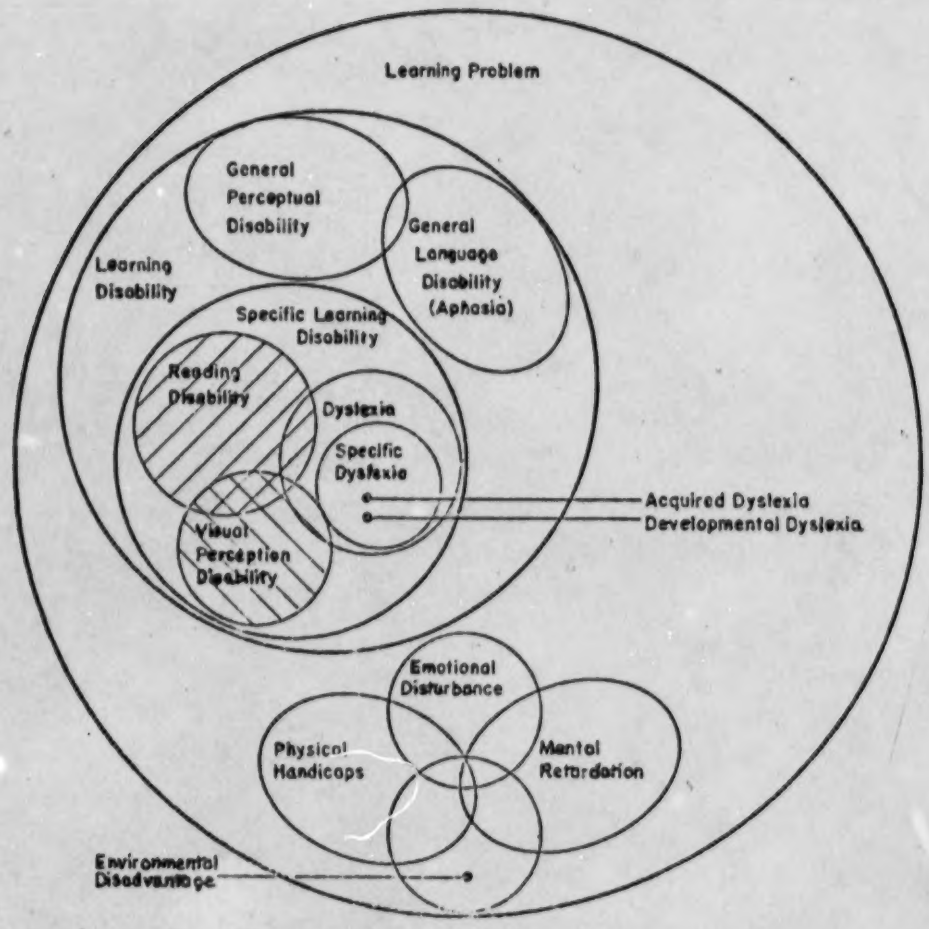

Figure 1. Iconic model of learning problems.

Table 1

Number of Individuals in Each Category in the Final Sample (n = 1,044)

Category	Number by Family Type	
	Affected	Control
Fathers of index children	125	125
Mothers of index children	125	125
Male index children	96	96
Under 10	64	64
10 or over	32	32
Female index children	29	29
Under 10	21	21
10 or over	8	8
Male sibs of index children	81	76
Under 10	21	23
10 or over	60	53
Female sibs of index children	77	60
Under 10	25	16
10 or over	52	44
Parents	250	250
Index children	125	125
Sibs of index children	158	136
All subjects	533	511

Table 2

Mean Ages in Years of Individuals in Each Category in the Final Sample

Category	Mean Ages by Family Type	
	Affected	Control
Fathers of index children	37.042	37.263
Mothers of index children	34.769	35.154
Male index children	9.510	9.616
Female index children	9.587	9.506
Male sibs of index children	12.110	11.923
Female sibs of index children	11.615	12.081
Parents	35.906	36.208
Index children	9.528	9.590
Sibs of index children	11.869	11.922
All subjects	22.594	23.252

Table 3

Tests in the Original (Unreduced) CFRS Battery and Their Sources

Test	Source
Peabody Individual Achievement Test	Dunn & Markwardt, 1970
Mathematics	
Reading Recognition	
Reading Comprehension	
Spelling	
Nonverbal Culture Fair Intelligence Test	Institute for Personality and Ability Testing, 1973
Goldman-Fristoe-Woodcock Test of Auditory Discrimination	Goldman, Fristoe, & Woodcock, 1970
Quiet Subtest	
Noise Subtest	
Colorado Perceptual Speed Test	Meredith, Singer, & DeFries, Note 4
Rotatable Letters and Numbers	
Wechsler Intelligence Scale for Children	Wechsler, 1949
Coding, Form B	
Digit Span	
Mazes	
Wechsler Adult Intelligence Scale	Wechsler, 1955
Digit Span	
Primary Mental Abilities	Thurstone, 1963
Spatial Relations	
Benton Right-Left Orientation	Benton, 1959
American Council on Education	American Council on Education, 1950
Figure Analogies	
Verbal Analogies	
Educational Testing Service	French, Ekstrom, & Price, 1963
Hidden Patterns	
Concealed Words	
Gestalt Completion	
Things	

Table 3 (Concluded)

Test	Source
Illinois Test of Psycholinguistic Abilities (Revised)	Kirk, McCarthy, & Kirk, 1968
Auditory Reception	
Visual Reception	
Auditory Association	
Visual Association	
Auditory Sequential Memory	
Visual Sequential Memory	
Verbal Expression	
Manual Expression	
Auditory Closure	
Grammatic Closure	
Visual Closure	
Sound Blending	
Visual Memory	Wilson et al., 1975
Finger Agnosia	Satz & Friel, 1973
Level 1	
Level 2	
Level 3	

Note. Adapted from "Familial Patterns of Impairment in Reading Disability," by T. T. Foch, J. C. DeFries, G. E. McClearn, and S. M. Singer, Journal of Educational Psychology, 1977, 69 (4), 319-320.

Table 4

Tests in the Reduced CFRS Battery

Age Group	Test
All Ages	Peabody Individual Achievement Test (PIAT): Mathematics, Reading Recognition,[a] Reading Comprehension,[a] Spelling[a]
	Nonverbal Culture Fair Intelligence Test (IPAT)[a]
	Auditory Closure (ITPA)
	Colorado Perceptual Speed Test[a]
	Coding B (WISC)[a]
	Spatial Relations (PMA)[a]
	Benton Left-Right Orientation Test[a]
Under 10 Subjects Only	Hidden Patterns (ETS)
	Illinois Test of Psycholinguistic Abilities (ITPA): Grammatic Closure, Visual Closure, Auditory Reception, Visual Reception, Auditory Association, Auditory Sequential Memory
10-and-over Subjects Only	Concealed Words (ETS)
	Gestalt Completion (ETS)
	Verbal Analogies (ACE)
	Digit Span (WISC or WAIS)

[a]Tests included in present study.

Note. Adapted from A Genetic Analysis of Specific Reading Disability, by F. I. Lewitter, unpublished master's thesis, University of Colorado, 1975, p. 26.

Table 5

Tests, Their Abbreviations, General Item Types, and General Visuoperceptual Content Classification

Test Name	Abbreviation	General Item Content	General Visuoperceptual Content Classification
Peabody Individual Achievement Test: Reading Recognition Subtest	RREC	Matching letters, naming letters, reading words aloud	Visual discrimination, object recognition, sequential crossmodal integration
Peabody Individual Achievement Test: Reading Comprehension Subtest	RCOMP	Silently reading sentence, then selecting picture representing material read	Visual symbolization
Peabody Individual Achievement Test: Spelling Subtest	SPELL	Discriminating between letters, choosing a standard spelling when examiner reads word orally	Visual discrimination, sequential crossmodal matching, object recognition
Benton Left-Right Orientation Test	BENT	Discriminating left and right on own body, then on picture of a person	Directional sense
Institute for Personality and Ability Testing Nonverbal Culture Fair Intelligence Test	IPAT	Choosing figure to complete a series, discriminating between figures, choosing a block to complete a design matrix, matching spatial relationships	Visual closure, visual discrimination, spatial relations
Wechsler Intelligence Scale for Children, Form R: Coding Subtest	CODE	Transcribing numbers into code, copying single symbols	Visual symbolization, visual-motor coordination
Primary Mental Abilities Test: Spatial Relations Subtest	PMA	Choosing object or figure to complete a series,[a] spatial orientation matching,[b] discriminating despite reversals and rotations[b]	Visual closure, spatial relations, directional sense
Colorado Perceptual Speed Test: Rotatable Letters and Numbers	PSPEED	Matching identical sets of letters and numbers, ignoring reversals or rotations	Visual discrimination, directional sense

[a]Under sixth grade. [b]Sixth grade and over.

Table 6

Canonical Correlations (R_{c1}) between the First Reading Variate and the First Visual Perception Variate, with Associated Eigenvalues (λ) for Significant Canonical Correlations (Hypothesis 12)

Groups	Family Types			
	Affected		Control	
	R_{c1}	λ	R_{c1}	λ
Fathers of Index Children	.771****	.594	.685****	.469
Mothers of Index Children	.620****	.384	.509****	.259
Male Index Children	.455		.535****	.286
Under 10	.499		.545*	
10 or over	.617		.594	
Female Index Children	.716		.686	
Under 10	.770		.841	
10 or over	1.000*****	1.000	1.000*****	1.000
Male Sibs of Index Children	.649****	.421	.659****	.434
Under 10	.927****	.859	.723	
10 or over	.659****	.434	.709****	.503
Female Sibs of Index Children	.564****	.318	.690****	.476
Under 10	.814		.854	
10 or over	.649***	.421	.729***	.531
All Parents	.710*****	.504	.595*****	.354
All Index Children	.423		.514****	.264
All Sibs	.607****	.368	.589****	.347
All Males	.658*****	.433	.557****	.333
Under 10	.550****	.303	.480	
10 or over	.697****	.486	.614****	.377
All Females	.560****	.314	.505****	.255
Under 10	.611****	.373	.651	
10 or over	.597****	.356	.505****	.255
All Family Members	.636*****	.405	.536*****	.287
Entire Sample	R_{c1} = .646*****		λ = .417	

*p < .01 **p < .005 ***p < .001 ****p < .0005 *****p < .0001

Table 7

Canonical Correlations (R_{c2}) between the Second Reading Variate and the Second Visual Perception Variate, with Associated Eigenvalues (λ) for Significant Canonical Correlations (Hypothesis 13)

Groups	Family Types			
	Affected		Control	
	R_{c2}	λ	R_{c2}	λ
Fathers of Index Children	.408***	.167	.410****	.168
Mothers of Index Children	.261		.468****	.219
Male Index Children	.173		.248	
Under 10	.306		.381	
10 or over	.307		.469	
Female Index Children	.349		.509	
Under 10	.590		.455	
10 or over	.789		.894	
Male Sibs of Index Children	.303		.298	
Under 10	.604		.492	
10 or over	.428		.498	
Female Sibs of Index Children	.493*	.243	.379	
Under 10	.408		.649	
10 or over	.390		.385	
All Parents	.373****	.139	.485****	.235
All Index Children	.176		.223	
All Sibs	.346***	.120	.328	
All Males	.281***	.079	.265****	.070
Under 10	.303		.209	
10 or over	.323****	.104	.344****	.118
All Females	.296***	.088	.373****	.139
Under 10	.592**	.351	.412	
10 or over	.255*	.065	.396****	.157
All Family Members	.279****	.078	.361****	.130
Entire Sample	R_{c2} = .320****		λ = .102	

*p < .01 **p < .005 ***p < .001 ****p < .0005 *****p < .0001

Table 8

Reading Test Loadings on First Reading Canonical Variate

Groups	Test Loadings		
	RREC	RCOMP	SPELL
Entire Sample	.288	.423	.407
Affected Families	.354	.457	.297
Control Families	.226	.285	.671

Table 9

Reading Test Loadings on Second Reading Canonical Variate

Groups	Test Loadings		
	RREC	RCOMP	SPELL
Entire Sample	.429	.930	-1.366
Affected Families	-.634	-.783	1.496
Control Families	.120	.984	-.844

Table 10

Visual Perception Test Loadings on First Visual Perception Canonical Variate

Groups	Test Loadings				
	BENT	IPAT	CODE	PMA	PSPEED
Entire Sample	.269	.493	.045	-.095	.599
Affected Families	.326	.544	.123	-.058	.432
Control Families	.106	.395	-.008	-.216	.863

Table 11

Visual Perception Test Loadings on Second Visual Perception Canonical Variate

	Test Loadings				
	BENT	IPAT	CODE	PMA	PSPEED
Entire Sample	.125	.713	.183	.235	-.975
Affected Families	-.021	-.739	-.413	.002	1.153
Control Families	.168	.692	-.038	.411	-.495

Table 12

Means and Results of Two-Way Analyses of Variance on Canonical Variate Scores: Entire Sample, (Hypotheses 3 and 4)

Canonical Variate Scores for Each Canonical Variate	Means				F-Values		
	Males n=599	Females n=445	Affected Family Members n=533	Control Family Members n=511	Sex	Family Type	Sex by Family Type
Canvar 1: First Reading Canonical Variate	.1032	-.1766	.4086	-.4590	26.011****	258.045****	14.967**
Canvar 2: First Visual Perception Canonical Variate	.1006	-.1678	.3087	-.3502	21.229****	132.283****	8.785*
Canvar 3: Second Reading Canonical Variate	.1622	-.2228	-.0122	.0087	39.589****	.064	3.020
Canvar 4: Second Visual Perception Canonical Variate	.2285	-.3211	.0194	-.0320	84.253****	1.005	6.083
Multivariate Analysis					34.334****	67.406****	5.403**

*$p < .01$ **$p < .001$ ***$p < .0001$ ****$p < .00001$

Table 13

Means and Results of Two-Way Analyses of Variance on Canonical Variate Scores: Parents, (Hypotheses 3 and 4)

Canonical Variate Scores for Each Canonical Variate	Means				F-Values		
	Fathers of Probands n=125	Fathers of Controls n=125	Mothers of Probands n=125	Mothers of Controls n=125	Sex	Family Type	Sex by Family Type
Canvar 1: First Reading Canonical Variate	.294	-.402	-.047	-.520	8.258*	53.622****	1.960
Canvar 2: First Visual Perception Canonical Variate	.331	-.368	.071	-.330	1.535	37.480****	2.766
Canvar 3: Second Reading Canonical Variate	.293	.285	-.086	-.261	27.643****	1.087	.900
Canvar 4: Second Visual Perception Canonical Variate	.516	.381	-.171	-.430	86.578****	6.013	.589
Multivariate Analysis					25.236****	15.978****	.968

*$p < .01$ **$p < .001$ ***$p < .0001$ ****$p < .00001$

Table 14

Means and Results of Two-Way Analyses of Variance on Canonical Variate Scores: Probands and Their Matched Controls Under 10 Years Old (Hypotheses 3 and 4)

Canonical Variate Scores for Each Canonical Variate	Means				F-Values		
	Male Probands n=64	Male Controls n=64	Female Probands n=21	Female Controls n=21	Sex	Family Type	Sex by Family Type
Canvar 1: First Reading Canonical Variate	1.208	-.388	1.242	-.710	1.433	265.863****	2.217
Canvar 2: First Visual Perception Canonical Variate	.786	-.390	.494	-.494	1.932	80.282****	.464
Canvar 3: Second Reading Canonical Variate	-.131	.044	-.432	-.057	1.598	2.671	.394
Canvar 4: Second Visual Perception Canonical Variate	-.101	.228	-.574	-.517	12.951**	3.220	.644
Multivariate Analysis					3.714*	68.902****	1.408

*$p < .01$ **$p < .001$ ***$p < .0001$ ****$p < .00001$

Table 15

Means and Results of Two-Way Analyses of Variance on Canonical Variate Scores: Probands and Their Matched Controls, 10 Years Old and More (Hypotheses 3 and 4)

Canonical Variate Scores for Each Canonical Variate	Means				F-Values		
	Male Probands n=32	Male Controls n=32	Female Probands n = 8	Female Controls n = 8	Sex	Family Type	Sex by Family Type
Canvar 1: First Reading Canonical Variate	1.270	-.653	1.587	-.432	2.404	195.508****	.078
Canvar 2: First Visual Perception Canonical Variate	.641	-.510	.577	-.410	.008	48.624****	.169
Canvar 3: Second Reading Canonical Variate	.118	.138	-.171	-.274	1.704	.001	.053
Canvar 4: Second Visual Perception Canonical Variate	-.364	-.037	-.304	-.514	.565	.972	.931
Multivariate Analysis					1.095	51.246****	.254

*p < .01 **p < .001 ***p < .0001 ****p < .00001

Table 16

Means and Results of Two-Way Analyses of Variance on Canonical Variate Scores: Siblings Under 10 Years Old (Hypotheses 3 and 4)

Canonical Variate Scores for Each Canonical Variate	Means				F-Values		
	Male Siblings of Probands n=21	Male Siblings of Controls n=23	Female Siblings of Probands n=25	Female Siblings of Controls n=16	Sex	Family Type	Sex by Family Type
Canvar 1: First Reading Canonical Variate	.789	-.424	.222	-.477	1.306	28.366****	1.978
Canvar 2: First Visual Perception Canonical Variate	.514	-.034	.112	-.481	5.821	5.225	.193
Canvar 3: Second Reading Canonical Variate	-.125	.315	-.042	-.460	1.629	.000	5.243
Canvar 4: Second Visual Perception Canonical Variate	.093	-.076	-.292	-.421	2.407	.438	.008
Multivariate Analysis					2.496	6.873***	1.892

*p < .01 **p < .001 ***p < .0001 ****p < .00001

Table 17

Means and Results of Two-Way Analyses of Variance on Canonical Variate Scores: Siblings 10 Years Old or More (Hypotheses 3 and 4)

Canonical Variate Scores for Each Canonical Variate	Means				F-Values		
	Male Siblings of Probands n=60	Male Siblings of Controls n=53	Female Siblings of Probands n=52	Female Siblings of Controls n=44	Sex	Family Type	Sex by Family Type
Canvar 1: First Reading Canonical Variate	.294	-.400	-.182	-.377	4.595	17.407***	4.964
Canvar 2: First Visual Perception Canonical Variate	.477	-.063	-.153	-.567	22.255****	16.153***	.276
Canvar 3: Second Reading Canonical Variate	.062	.263	-.375	-.368	13.418**	.604	.452
Canvar 4: Second Visual Perception Canonical Variate	.178	.350	-.107	-.425	14.048**	.148	3.213
Multivariate Analysis					11.555****	5.706**	2.156

*$p < .01$ **$p < .001$ ***$p < .0001$ ****$p < .00001$

Table 18

Single-Parent, Single-Index-Child Correlations for Canonical Variate Scores in Affected and Control Families
(Hypothesis 5)

	Affected Families				Control Families			
	r_{FS}	r_{MD}	r_{MS}	r_{FD}	r_{FS}	r_{MD}	r_{MS}	r_{FD}
Canvar 1: First Reading Canonical Variate	.02	.43*	.35****	.45*	.12	.21	.14	.07
Canvar 2: First Visual Perception Canonical Variate	.24*	.07	.14	.31	.15	.39*	.03	.41*
Canvar 3: Second Reading Canonical Variate	.21*	-.05	.05	.33	.17	.26	.14	.42*
Canvar 4: Second Visual Perception Canonical Variate	.11	.16	.09	.04	.04	.21	.13	.03

*p < .05
**p < .01
***p < .005
****p < .001

Table 19

Familial Resemblance for Canonical Variate Scores in Affected and Control Families[a/]
(Hypotheses 6 and 7)

Canonical Variate Score	Spouse Correlation		Regression of midchild on midparent[b/]		Sibling Intraclass correlation[c/]	
	Parents of probands	Parents of controls	Affected Families	Control Families	Siblings of probands	Siblings of controls
Canvar 1: First Reading Canonical Variate	.31±.09****	.34±.09****	.34±.09****	.27±.09***	.04±..07	.19±.09***
Canvar 2: First Visual Perception Canonical Variate	.25±.09***	.07±.09	.32±.07****	.32±.09****	.19±.09****	.24±.09****
Canvar 3: Second Reading Canonical Variate	-.02±.09	-.06±.09	.25±.08***	.24±.10*	-.03±.07	.08±.08
Canvar 4: Second Visual Perception Canonical Variate	.03±.09	.07±.09	.26±.10**	.23±.12*	.08±.08	.16±.09***

[a/] Coefficients ± standard error.

[b/] Upper-bound estimate of "narrow sense" heritability.

[c/] Estimate of one-half of "narrow sense" heritability.

*p < .05
**p < .01
***p < .005
****p < .001